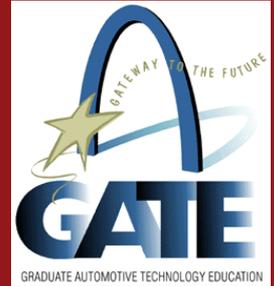


# GATE: ENERGY EFFICIENT VEHICLES FOR SUSTAINABLE MOBILITY



PROJECT T1022

Semiannual report, Year 3 – June 2014

PI: Giorgio Rizzoni

The Ohio State University Center for Automotive Research  
and Departments of: Mechanical and Aerospace Engineering;  
Electrical and Computer Engineering; Materials Science and  
Engineering  
June, 2014

*\*This presentation does not contain any proprietary, confidential, or otherwise restricted information.*

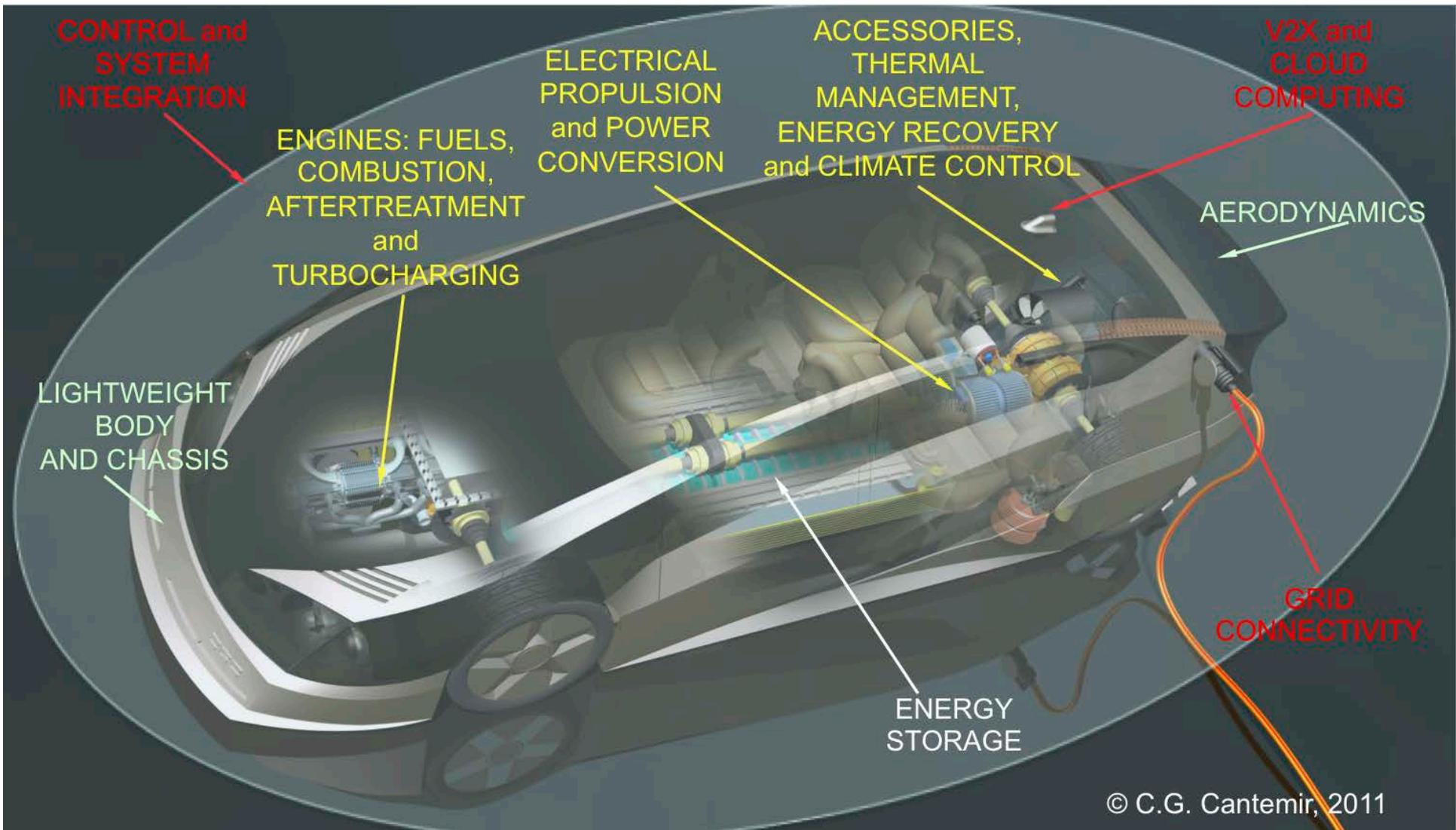
CENTER FOR AUTOMOTIVE RESEARCH

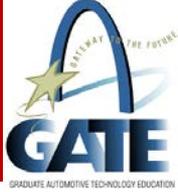


**THE OHIO STATE  
UNIVERSITY**  
COLLEGE OF ENGINEERING

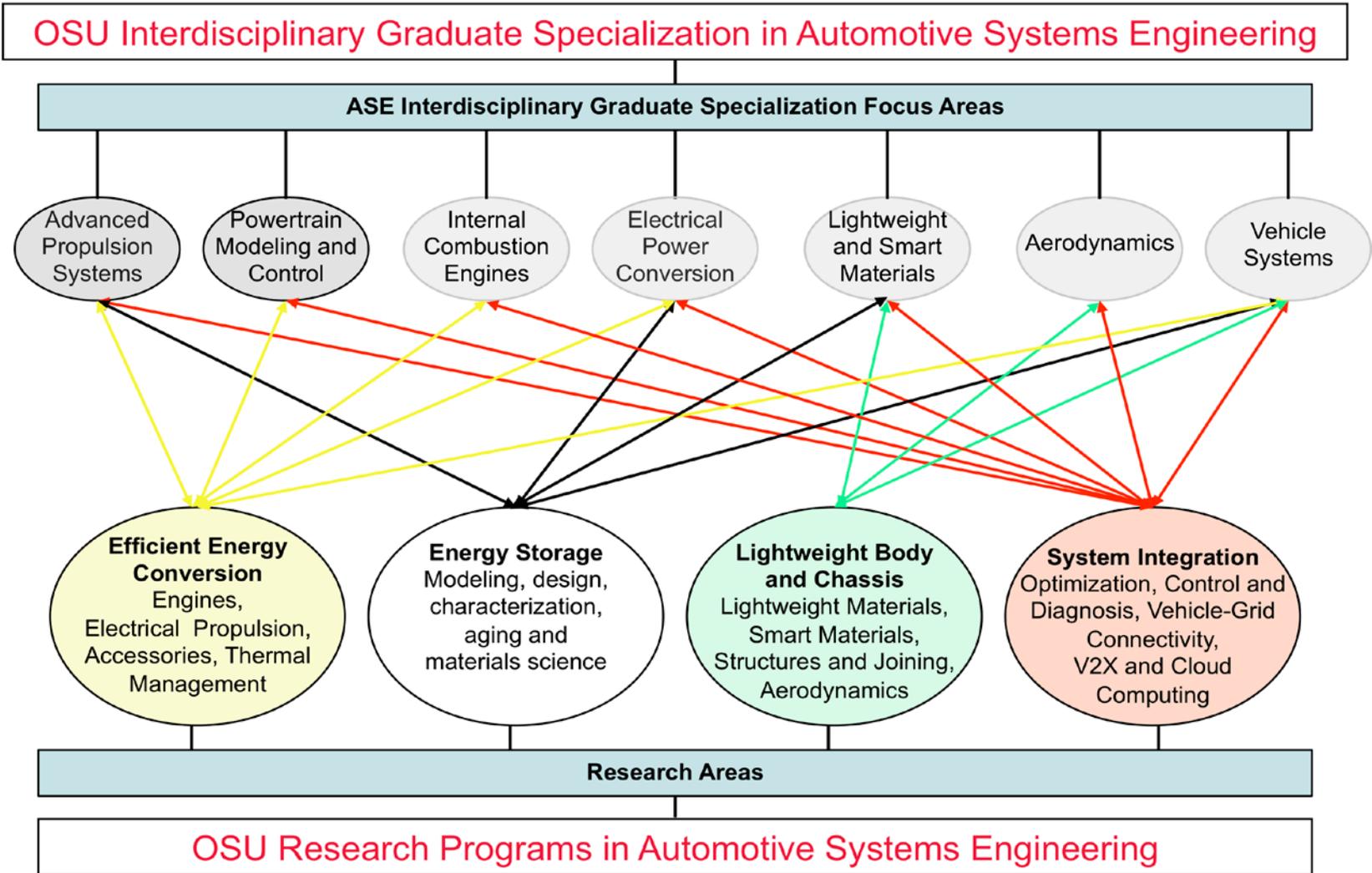


# BACKGROUND: TECHNICAL AREAS RELEVANT TO OSU PROGRAM





# BACKGROUND: GRADUATE SPECIALIZATION AND RESEARCH AREAS





## OVERVIEW, AS OF JUNE 2014

### Timeline

- Project start date  
10/01/2011
- Project end date:  
09/30/2016
- Percent complete: 50%

### Budget

- Total project funding:
- \$4,420,951
  - DOE share: \$907,026
  - Contractor share: \$3,513,925
- Funding in FY13: \$225,000
- Funding for FY14: \$181,247  
(budgeted)
- \$418,819 spent (46.2%)
  - as of 3/31/2014

### Barriers

- Fuel Economy
- Lightweight materials and structures
- Public acceptance of electric vehicles

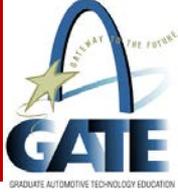
### Partners

- General Motors Corp.
- Honda OSU Partnership
- Venturi Automobiles
- CAR Industrial Consortium
- SMART@CAR Consortium



## YEAR 3 MILESTONES (FROM PMP)

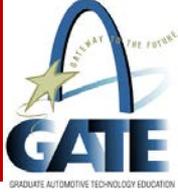
- Task 3.1: Recruit GATE fellows **completed**
- Task 3.2: Update recruitment material and publicize GATE program **completed**
- Task 3.3: Scheduled course offerings in APS core area (**completed**)
- Task 3.3: Scheduled course offerings in PMC core area (**completed**)
- Task 3.5: Scheduled course offerings in ICE core area (**completed**)
- Task 3.6: Scheduled course offerings in EPC core area (**completed**)
- Task 3.7: Scheduled course offerings in LWS core (**completed**)
- Task 3.8: Scheduled course offerings in AE core area (**completed**)
- Task 3.9: Scheduled course offerings in VS core area (**completed**)
- Task 3.10: Permanent offering of new system integration course (VS core area) (*in progress*)
- Task 3.11: Offering of targeted courses from above core areas to industrial partners via distance learning (**completed**)
- Task 3.12: Increase industrial support by seeking additional fellowship funding (*in progress*)
- Task 3.13: Track graduation and employment of GATE Fellows (**completed**)
- Task 3.14: Report to DOE and Industrial Advisory Board and participation in DOE Merit review (*will be complete when the semi-annual report is presented at AMR*)



## TECHNICAL ACCOMPLISHMENTS

- GATE Fellows currently funded by **DOE**:

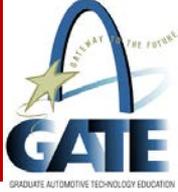
Fellow Name	Advisor	Est. Graduation	Research Topic
Alexander Bartlett, ME Ph.D. pre-candidate	Giorgio Rizzoni	Dec 2015	State of charge and state of health estimation of lithium-ion batteries using reduced-order electrochemical models
Katherine Bovee, ME Ph.D. pre-candidate	Giorgio Rizzoni	August 2015	A novel control-for-driveability methodology for hybrid electric vehicles
John Frederick, ME Ph.D. pre-candidate	Ahmet Selamet	May 2016	Advanced Knock - Engine Heat Transfer and Combustion
Danielle Fredette, ECE Ph.D. pre-candidate	Ümit Özgüner	May 2016	Human driver modeling and comparison of methods using a driving simulator
Scott Schnell, ME, Ph.D. pre-candidate	Junmin Wang	May 2017	
Andrew Klarner, MSE Ph.D. pre-candidate	Alan Luo	May 2017	Development of Integrated Die Casting Process For Large Thin-Wall Magnesium Applications



## TECHNICAL ACCOMPLISHMENTS

- GATE Fellows currently funded by **Partners (HPP, GM)**:

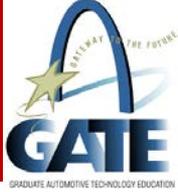
Fellow's Name	Advisor	Est. Graduation	Research Topic
Guodong Fan	Marcello Canova, Giorgio Rizzoni, MAE	Dec 2015	First-principles electrochemical and thermal modeling of battery packs
Engin Özatay	Ümit Özgüner, ECE	Dec 2014	Velocity Profile Optimization and Dynamic Routing for Every Day Driving
Amanda Hyde	Shawn Midlam-Mohler	May 2014	Traction Control for EcoCAR 2
Eric Gallo	Shawn Midlam-Mohler	Summer 2014	Optimal Control for a Series HEV
Jason Ward	Shawn Midlam-Mohler	2016	Model-Based Control for an E85 Engine



## TECHNICAL ACCOMPLISHMENTS

- GATE Fellows currently funded by **Partners (Venturi)**:

Fellow	Advisor	Est. Graduation	Research Topic
David Cooke, MS, ME	Rizzoni	December 2014	System Integration of the Buckeye Bullet 3 Land Speed Record electric vehicle
Austin Krohn, MS, ECE	Rizzoni	May 2014	Analysis and optimization of electric drive systems for the Buckeye Bullet 3 Land Speed Record electric vehicle
Robert Kromer, MS, ECE and MAE	Canova, Rizzoni	May 2014	Modeling, simulation and control of the Buckeye Bullet 3 Land Speed Record electric vehicle
Lingchang Wang, MS, ECE	Rizzoni	May 2014	Design and management of a battery systems for a Land Speed Record electric vehicle
Casey Clark, AE	Rizzoni, Gregory	May 2014	Aerodynamic design optimization of the Buckeye Bullet 3 Land Speed Record electric vehicle
Evan Maley, MS, ME	Rizzoni	May 2015	Design and analysis of the suspension system for the Buckeye Bullet 3 Land Speed Record electric vehicle
Luke Kelm, MS, ME	Rizzoni	May 2015	Design and analysis of the mechanical transmission system for the Buckeye Bullet 3 Land Speed Record electric vehicle



## TECHNICAL ACCOMPLISHMENTS

- Past GATE Fellows graduates and employment (if applicable)

<b>Advisor:</b>	<b>Student (program):</b>	<b>Status</b>	<b>Employment</b>	<b>Degree</b>
Selamet	Dehner, Ricky D. (ME)	In progress (funded by Ford)		Ph.D.
Canova	Hammond, Irus Dell (ME)	Graduated	John Deere	M.S.
Wang, Jin/Xu	Herrera, Luis (ECE)	In progress (funded by Air Force)		Ph.D.
Heremans	Jaworski, Chris (ME)	Graduated		Ph.D.
Daehn	Johnson, Jason (MSE)	In progress		Ph.D.
Ozguner	Khayyer, Pardis (ECE)	Graduated		Ph.D.
Dapino	Scheidler, Justin (ME)	In Progress (funded by NASA)		Ph.D.
Canova	Zhou, Junqiang (ME)	In progress		Ph.D.
Rizzoni	Gong, Qiuming (ME)	Graduated	Ford SMT	Ph.D.
Ozguner	Wollaeger, James (ECE)	Graduated	Bosch	MS
Wang, Junmin	Yan, Fengjun (ME)	Graduated	McMaster Univ., Hamilton, ON, CAN	Ph.D.
Gregory	Tomac, Mehmet (AE)	Graduated	Abdulah Gul University, Turkey	Ph.D.
Midlam-Mohler	Garcia, Andrew (ME)	Graduated	GM	MS
Midlam-Mohler	Ma, Teng (ME)	Graduated	AVL	MS
Midlam-Mohler	Yard, Matthew (ME)	In progress (May 2015)		MS
Wang, Junmin	Chen, Yan (ME)	Graduated	Ford	Ph.D.
Rizzoni	Tang, Li (ME)	In progress (May 2016)		Ph.D.
Rizzoni	Krohn, Austin	In progress (May 2014)		MS
Rizzoni	Hyde, Amanda (ME)	In progress (May 2014)	Hired by GM	MS
Rizzoni	Kromer, Robert (ME, ECE)	In Progress (May 2014)	Hired by Ford	MS
Rizzoni	Wang, Lingchang (ME, ECE)	In Progress (May 2014)		MS
Rizzoni/ Gregory	Clark, Casie (AE)	In Progress (May 2014)	Hired by Lockheed- Martin	MS



## TECHNICAL ACCOMPLISHMENTS

### Summary:

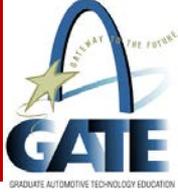
- Currently Funded GATE Fellows: 18 (6 by DOE; 12 by Partners)
- Funded GATE Fellows since beginning of the program: 36 (including current)
- GATE Graduate Employment:
  - Ford (3)
  - GM (2)
  - Bosch (1)
  - AVL (1)
  - John Deere (1)
  - Lockheed-Martin (1)
  - Academic positions (2)



## TECHNICAL ACCOMPLISHMENTS

### Collaborations

- The GATE program leverages support from **General Motors Corporation** and the **Honda-OSU Partnership Program (HPP)**. These partners provide support for 3 fellowships/year for the duration of the program. General Motors recently increased its support of the program.
- **Venturi Automobiles** has provided support for 7 GATE Fellows, as part of the Venturi Buckeye Bullet 3 Land Speed record Electric Land Speed Record program
- Two additional Fellow appointments are supported by the **CAR Industrial and SMART@CAR consortia**.



## CAR INDUSTRIAL CONSORTIUM

- The **CAR Industrial Consortium** focuses on the development of pre-competitive research whose outcomes are shared among industrial partners.
- Current partners: **Bosch, Chrysler, Cummins, Ford, GM, Honda, Lubrizol, Renault, Tenneco, TRC Inc.** Consortium members have actively recruited among GATE graduates at OSU since 1999.
- Currently, three trust areas concentrate on research areas that are unique to OSU and offer consortium members an opportunity to select research projects:
  - **Advanced Propulsion Systems (APS);**
  - **Intelligent Transportation Systems (ITS);**
  - **Lightweight Structures (LWS).**

### Current projects:

- *Life estimation of lithium-ion batteries for PHEVs*
- *Thermal and electrochemical modeling of PHEV/EV Li-ion battery packs;*
- *Model-based investigation of lean gasoline PM and NOx control*
- *Light-duty natural gas engine characterization*





## SMART@CAR CONSORTIUM

- The **SMART@CAR Consortium** is an industry driven research and development program focused on Plug-in Electric Vehicles (PEVs) and intelligent charging.
- Current partners: **American Electric Power, Clean Fuels Ohio, FirstEnergy, SDGE, Renault, Ford, GM, Chrysler, UT Dallas, TE Connectivity.**
- Topics for research, development, and demonstration are determined by the members on an on-going basis. Currently on-going projects include:

### Topics:

- Electric Vehicle Penetration and Adoption in Ohio
- DC Fast Charging Impact on Electric Grid
- Microgrid Testbed and Installation at CAR
- Secondary Life of Automotive Batteries: Aging and Economic Analysis



CHRYSLER



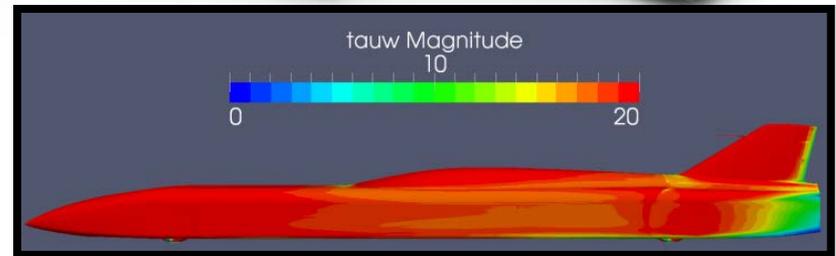


## Technical Accomplishments – Venturi Buckeye Bullet 3

Venturi Buckeye Bullet Racing is a land speed racing project with the goal of exceeding 400 MPH with an electric vehicle for the first time in history. Project partners include **OSU-CAR** and **Venturi Automobiles**.

### Key Thrust Areas

- Electric powertrain development, integration, and control
- Aerodynamic optimization for drag reduction and stability
- Li-ion battery management and rapid charging technology
- Advanced energy storage integration
- Lightweight structures
- High speed wheel package development (custom bearing, cv joint, wheel, and tire)





## Technical Accomplishments – Venturi Buckeye Bullet 3

### 2013 Accomplishments

- Component level testing of all systems
- Complete design freeze of vehicle
- Vehicle construction
- Initial road testing up to 100 mph



### Employers of Recent Graduates

- Ford - SMT
- A123 Systems
- Boeing Co.
- Lockheed Martin
- Northrop Grumman
- Mercedes Formula 1
- Battelle Memorial Institute



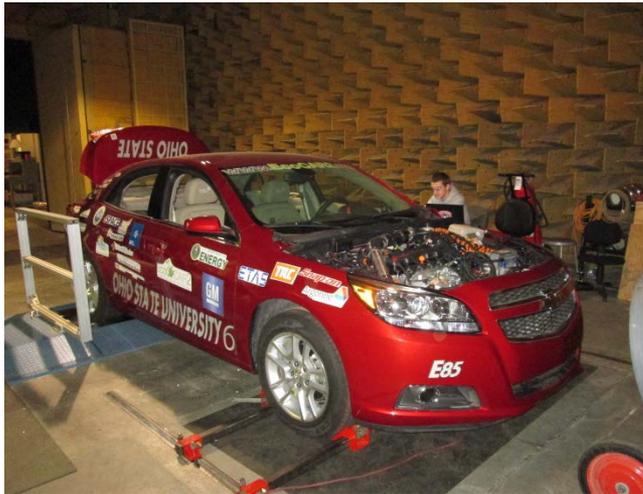


## Technical Accomplishments – EcoCAR 2

- Developed Parallel-Series Plug-in Hybrid Electric Vehicle (PHEV) for EcoCAR 2 competition
- OSU team placed 3<sup>rd</sup> overall last year in the competition
  - Also won 1<sup>st</sup> place in Business Program and 2<sup>nd</sup> place in Communications Program
- OSU team has one of the more complex EcoCAR vehicles
  - Team developed custom control software for their E85 engine and automated manual transmission
  - Vehicle supervisory controller runs an online optimization strategy called the Equivalent Consumption Minimization Strategy



## Technical Accomplishments – EcoCAR 2



- Team has made multiple electrical/mechanical refinements to the vehicle this year that include:
  - Light weighting components
  - Reducing electrical accessory loads
  - Increasing robustness of overall subsystems
- Vehicle testing done by the team this year includes:
  - Refining custom emissions control system for engine
  - Automating a manual transmission
  - Testing energy management algorithms for fuel economy and emissions
  - Testing overall vehicle for good performance characteristics



## Technical Accomplishments –Buckeye current

### Buckeye Current

**Racing** focuses on the design, build and racing of fully electric motorcycles at the Isle of Man TT Zero.

Though the team was only founded in 2011, it holds the record for being the world's fastest collegiate electric motorcycle in the world's toughest motorcycle race.



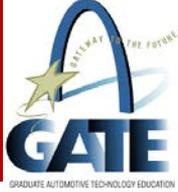


## Technical Accomplishments –Buckeye current

### Team Accomplishments:

- Competing on a professional (not just collegiate) level
- 90% Undergraduate involvement and 100% undergraduate team leadership
- 9 month build, design and test cycle for each vehicle
- Ground-up build and design of data-logging and battery management systems
- System integration of electric powertrain components





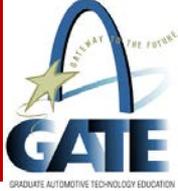
## GATE COURSES OFFERED IN ACADEMIC YEAR 2013-14

- **Core Focus Area: Advanced Propulsion Systems, APS**

<p>ME 7384 - Energy Modeling, Simulation, Optimization and Control of Advanced Vehicles (Guezennec) (20 OSU+7 GM students). <i>Also offered to GM Technical Education Program</i></p>	<p>ME 7383 - Electrochemical Energy Conversion and Storage Systems (Canova, Guezennec) (18 OSU+6 GM students) <i>Also offered to GM Technical Education Program</i></p>
<p><i>Autumn semester</i></p>	<p><i>Spring semester</i></p>

- **Core Focus Area: Powertrain Modeling and Control, PMC**

<p>ME 7236 – Powertrain Dynamics (Rizzoni and Srinivasan); <i>Offered only to GM Technical Education Program (9 GM students).</i></p>	<p>ECE 5554 Powertrain Control (Rizzoni) <i>Offered only to GM Technical Education Program (4 GM students).</i></p>
<p><i>Autumn semester</i></p>	<p><i>Spring semester</i></p>



• **Core Focus Area: Internal Combustion Engines, ICE**

ME 5530 – <b>Internal Combustion Engines</b> (Selamet); 53 students	ME 5531 – <b>Automotive Powertrain Laboratory</b> (Midlam-Mohler); 17 students
<i>Autumn semester</i>	<i>Spring semester</i>
ME 8322 - <b>Diesel Engine Systems Control</b> (Wang) ; 8 students	ME 5427 – <b>Introduction to Turbomachinery</b> (Canova); 30 students
<i>Autumn semester; odd years</i>	<i>Spring semester</i>

• **Core Focus Area: Electrical Power Conversion, EPC**

ECE 5025 - <b>Power Electronics Devices, Circuits, and Applications</b> (Jin Wang); 54 students (OSU and GM)	ECE 5041 - <b>Electric Machine Fundamentals</b> (Xu); 61 students
<i>Autumn semester</i>	<i>Spring semester</i>
ECE 5541 - <b>Sustainable Energy and Power Systems II</b> (Illindala); 61 students	ECE 5127 - <b>Power Electronics Laboratory</b> , (Xu); 35 students
<i>Spring semester</i>	<i>Autumn semester</i>



• **Core Focus Area: Lightweight and Smart Materials, LWS**

ME 5374 - <b>Smart Materials and Intelligent Systems</b> (Dapino); 21 students <i>Spring semester</i>	MSE 4181 - <b>Materials Selection (Daehn)</b> ; 36 students <i>Autumn semester</i>
MSE 5605 - <b>Quantitative Introduction to Materials Science</b> (Daehn); 30 students <i>Autumn semester</i>	WE 7101 - <b>Welding Metallurgy I</b> (Babu); 40 students <i>Spring semester</i>

• **Core Focus Area: Vehicle Systems, VS**

ME 5234 - <b>Vehicle Dynamics</b> (Heydinger); 49 students <i>Spring semester</i>	ME 8322 - <b>Autonomy in Vehicles</b> (Özgüner) ; 15 students <i>Spring semester; even years</i>
ME 5339 - <b>Simulation techniques for dynamic system analysis and design</b> (Canova); 28 students <i>Autumn semester</i>	ME 4194 - <b>Applied Project Management and System Engineering</b> (Midlam-Mohler), 16 students <i>Autumn semester</i>



## SUMMARY

- The proposed program is fully responsive to the DOE GATE FOA:
  - Comprises a broad range of research programs (funded by the automotive industry and by government agencies);
  - Provides outstanding training opportunities for a significant number of graduate students (75 graduate students currently employed at OSU CAR);
  - Facilitates creation of automotive engineering professionals capable of supporting the future needs of the automotive industry.
- The support and cost share provided by OSU and by our industry partners clearly demonstrates the relevance of the proposed program to the industry.
- OSU College of Engineering Career Services office reports that in the past ten years, 11 automotive and commercial vehicle OEMs and 20 suppliers have hired 720 interns and co-ops and 376 full time engineers **from OSU.**